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RAREFACTION WAVE GUN TANK MAIN ARMAMENT DEMONSTRATOR

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RAREFACTION WAVE GUN TANK MAIN ARMAMENT DEMONSTRATOR

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ABSTRACT

RArefaction waVe guN (RAVEN) propulsion is a widely acclaimed method to impart maximum energy into a projectile while imparting the least recoil momentum and thermal heating to the launcher. It was originally conceived in 1999 to meet the ambitious lethality and strategic deployability objectives of the future combat systems (FCS) to drive off a C130 transport ready for combat. RAVEN was removed from consideration to meet FCS lethality requirements due to the perceived immaturity of the technology in a "risk avoidance" program philosophy. This paper presents the experimental results of a brass-board tank main armament demonstration system based upon RAVEN propulsion. This technology profoundly alters the system integration options for guns.

INTRODUCTION

The tank main armament demonstrator operates on the rarefaction wave gun principle. In such a gun the breech is intentionally opened while the projectile is still traveling down the barrel. This causes a dramatic drop in chamber pressure as pressure rapidly bleeds off through the open breech. Although at first it would be anticipated projectile acceleration would be compromised, such losses cannot occur until the pressure loss wave (i.e., rarefaction wave) reaches the bullet. The speed of this rarefaction wave is limited to the speed of sound within the propellant gas. The propulsion of the bullet can only be compromised after the bullet 'hears' the venting.

The implication is that if the bullet leaves the muzzle, as the rarefaction wave reaches it, the muzzle velocity will not be compromised. We call this synchronized timing. Venting later will never slow the bullet and venting earlier will progressively slow the bullet more while more recoil is reduced or eliminated. It has been shown that synchronized operation typically occurs when venting commences when the bullet has traveled between one fourth and one third of its travel down the bore.

Fig. 1. Image of 105mm RAVEN firing.

Fig. 1. is a video snapshot of the 105mm RAVEN firing at Ares, Inc., Port Clinton, OH, on 13 August 2008. The muzzle is to the right, and the RAVEN nozzle integrated to the breech is to the left. Unlike prior art recoilless rifles, the rearward venting commenced nominally two milliseconds prior to muzzle exit of the projectile. Directed through an engineered expansion nozzle to cool the gas and maximize developed thrust; the rearward discharge indicates reduced flash and improved directionality relative to the muzzle flash.

This paper extends the results of a prior presentation[1] from six shots to twelve.

RAREFACTION AND SHOCK WAVES

Although a positive pressure shock wave can move through a column of gas at faster than the speed of sound, a rarefaction wave cannot. A rarefaction wave reduces gas pressure and density behind the wave front. As gas density is reduced, it becomes more rarefied. This rarefaction progressively cools the gas, decreasing its sound speed and weakening the pressure loss gradient as the wave propagates.

As such waves propagate through the gas column, the local flow velocity of the column must be added to the local sound speed to properly compute the rarefaction wave velocity. In the case of a synchronized RAVEN, the local gas velocity may initially be approximated as zero upon first opening the breech and that of the projectile's muzzle velocity upon reaching it at shot exit. Thus, an average gas velocity contribution to the rarefaction wave of half the muzzle velocity provides a reasonably accurate first estimation. A reasonable first approximation of the speed of sound within a gun is one thousand meters per second. Dividing the length of the gun by the sum of sonic and average gas velocity estimates the extent to which RAVEN venting may precede shot exit without any loss in muzzle velocity.

Accurate simulation of rarefaction wave propagation has been undertaken using a lumped parameter interior ballistic code and two separate one dimensional interior ballistic codes. The closed breech code NOVA[2] was employed[3] to determine rarefaction wave propagation rates through several gun systems without computing effects behind the wave front. A lumped parameter code incorporating blow-back recoil was developed to predict wave front propagation rates in support of the design of RAVEN technology demonstrators[4]. A new one-dimensional code named Rarefaction wAve Recoil (RAR) was specifically developed to model RAVEN[5]. It explicitly simulates the rarefaction wave process to include estimation of thrust produced and reduction of thermal heating of the bore.

PRIOR DEMONSTRATORS

35MM RAVEN

The 105mm RAVEN was preceded by a 35mm blow back bolt operated RAVEN. Unlike a traditional breech ring and block which provides containment of chamber pressure by stresses developed within interlocking steel threads or lugs, a blow back configuration provides inertial containment. It is not structurally fixed to the cannon, rather, it is allowed to be displaced rearward much as the bullet is allowed to travel forward towards the muzzle. As typified by the M3A1 45 caliber submachine gun (a.k.a., grease gun) blow back requires a far more massive bolt than bullet. This ensures that the resulting stretch of the cartridge case is sufficiently small to prevent rupture and maintain reliable obturation (pressure seal) of the chamber[6].

The blow-back approach was modified for the 35mm RAVEN demonstration to intentionally rupture the cartridge case head from the body. It was then allowed to recoil within a chamber extension a fixed distance prior to 'uncorking.' A nylon obturator was introduced to the head to maintain a sliding pressure seal in analogy to the rotating band fixed to the bullet. Variation in vent timing was provided by using two different weight bolts, nominally 21Kg and 36Kg and four different length vent extensions. Total recoil stroke to vent was varied from nominally 40mm to 90mm.

Using this approach, recoil momentum was cut by half and barrel heating was reduced by 40%. Interestingly, the reverse blow down of the RAVEN was observed to pneumatically eject the ruptured cartridge case body from the chamber[4].

MRAAS

Following the successful trials in 35mm, the successful large caliber RAVEN was engineered using design and hardware assets remaining from the 105mm† Multi-Role Armament and Ammunition System (MRAAS) program. MRAAS incorporated a novel swing chamber and cased telescoped ammunition that provided 120mm tank gun lethality from an armament system that lent it self to compact combat system integration.

Modifications to the gun and ammunition design to achieve RAVEN propulsion were minimized to control costs, accelerate schedule, and minimize risk.

105MM RAVEN HARDWARE

As shown in Fig. 2., the 105mm RAVEN borrowed the MRAAS swing chamber ammunition interface. This provides a straight forward and simple means to load ammunition. The nozzle is integrated to the left and shot travel is to the right.

Incorporated within the breech end is a fixed annular vent and expansion nozzle within which a 105mm blow back bolt is positioned. Centered within the aft end of the cartridge case is a 105mm consumable disk. Upon ignition of the cartridge, the consumable disk is pressed into the forward face of the blow back bolt and the vent mechanics proceed with great similarity to the 35mm demonstrator. However, since the bolt and projectile have the same diameter, the 105mm RAVEN imparts neither forward momentum nor rearward recoil to the launch tube. This eliminates a primary load that drives the gun dynamics (e.g., gun whip) that contribute to dispersion.

A second advance embodied within the 105mm demonstrator is the application of variable orifice hydraulic recoil brakes and recuperators. These arrest the rearward recoil motion of the bolt and return it to its battery position. The bolt is coupled to the recoil cylinders through the outer expansion nozzle housing. Four vanes cast into the nozzle, as seen in Fig. 3, merge to support the coaxial bolt. This allows a convenient integration method for the recoil cylinders and allows a portion of the thrust generated to directly arrest the recoil motion.

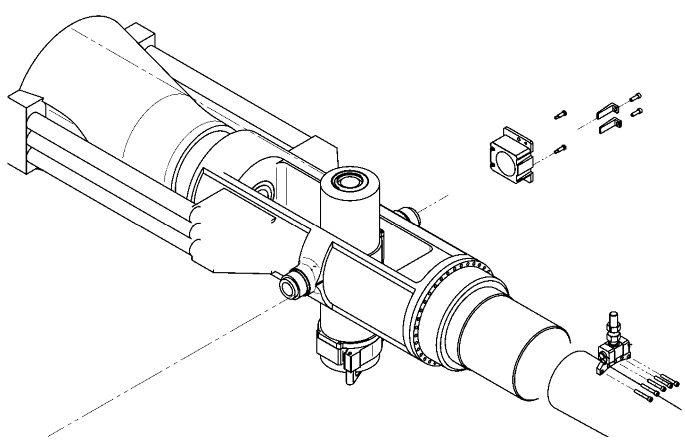

Fig. 2. 105mm RAVEN swing chamber.

† Although the MRAAS incorporated a 105mm bore, it was not compatible with standard 105mm tank gun ammunition employed by the M68 gun system. Principle differences included 1) a larger chamber volume for more propellant and 2) a smooth bore that is better suited for kinetic energy and guided projectiles than the rifled bore of the M68.

The coaxial configuration of inner and outer expansion nozzles may be appreciated by the line drawing of Fig. 4, which shows a centerline cross section of the bolt, nozzles, chamber, and gun tube with the bolt fully forward in its battery position. Vent timing may be altered by the use of different bolt faces. Blunt faced bolts require a greater recoil distance to vent. Progressively more conical bolts vent earlier. This is shown in Fig. 5. where the two distances listed indicate first the distance to initiation of the venting and second the approximate distance to fully open the vent. Between these two positions, choked flow is anticipated within the annular gap between the bolt face and nozzle.

Fig. 3. RAVEN assembly team.

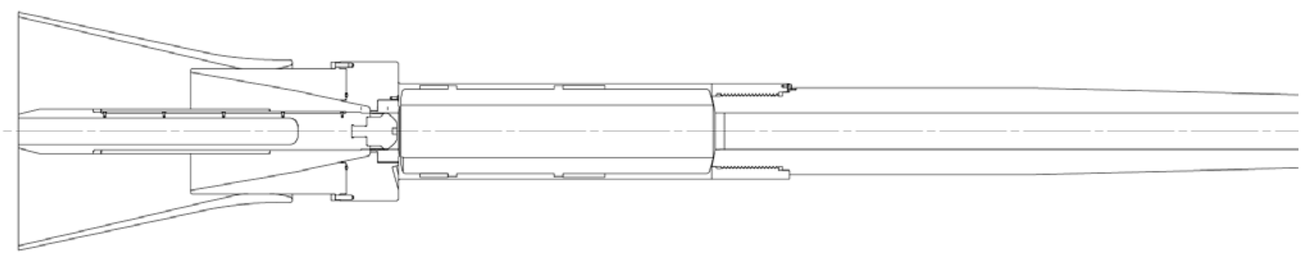

Fig. 4. 105mm RAVEN line drawing .

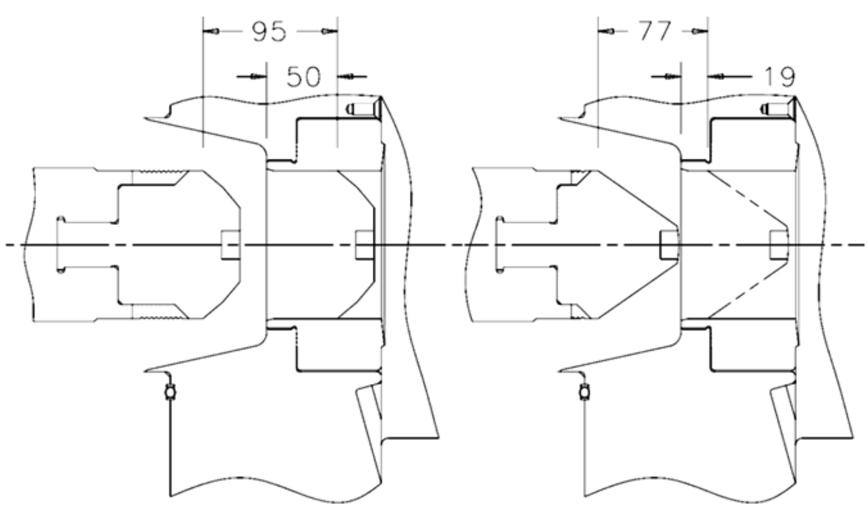

Fig. 5. Millimeters of displacements to initiate and fully open the vent for a blunt and conical bolt face.

This novel approach to parametrically alter vent timing constitutes a substantial simplification from the prior 35mm demonstrator. The 35mm RAVEN required the use of chamber extension inserts that effectively changed the length of the chamber to effect earlier or later venting. Simply changing the bolt face was a more pragmatic solution to facilitate changes in vent timing at this much larger demonstration scale. However, this novel interface does increase ullage[†]. It should be appreciated that this technique is used for the purposes of brass board technology demonstration. An objective RAVEN weapon system would tune propellant configuration and vent geometry for optimal ballistic performance at its design point.

TEST RESULTS

Twelve shots were successfully fired from February to October of 2008 with no major component failure or unexpected dynamic response. The results are tabulated in Table 1. It includes predicted results using RAR and experimental findings. The first three shots were fired at reduced charge and have been removed from the table. They remain available in a prior paper[1]. Two groups were fired. Group A averaged 6.8Kg of propellant with Group B averaging 7.0Kg. Within each group, shot data is presented in the order of decreasing distance to vent. Decreasing the distance to vent hastens venting.

Muzzle velocity was measured using standard screens and compares well with predictions. Chamber pressure was recorded using a novel integrated transducer and recorder unit inserted into the chamber. The experimental readings are consistently lower than predicted. As the muzzle velocities compare favorably and the experimental trends are consistent, the calibration is suspect. Experimental momentum was inferred by recording the velocity of components during recoil. Its fidelity is subject to frictional affects, but compares reasonably well with predicted values. Shot number 9, with the earliest venting configuration, exhibits muzzle velocity and momentum loss consistent with pre-synchronized vent timing.

For a point of reference, the predicted results for a close-breech configuration, scheduled as shot 17 are presented supporting recoil reduction by a factor of two.

DISCUSSION

The primary objective of the 105mm RAVEN was to demonstrate increased technology maturity for large caliber applications. It was very successful in this endeavor.

The large caliber hardware demonstration program was focused upon build and test. Instrumentation challenges degraded the quality of data collection across the board during this first series of tests. Challenges in inferring experimental momentum using integrated strain gauges required the use of velocity measurement with correction terms for secondary recoil brake forces as a function of velocity. Temperature and pressure measurements were subject to data collection challenges that were not adequately resolved during this testing.

The focus on build and test also resulted in unintended consequences in ballistic performance. Charge mass is subject to variation that is not negligible from round to round. It should be understood that these are one of a kind test rounds and neither offer the consistency nor design optimization of a fielded weapon. In particular, the increasing ullage associated with earlier vent geometries predictably reduces peak pressure and muzzle velocity and would never be tolerated in a design intended to be fielded. (This would be true in a closed breech configuration as well.) It is unfortunate that this correlation detracts from the clarity of the RAVEN concept that venting after synchronized timing will have no effect on muzzle velocity.

A second round of testing is scheduled to commence in the summer of 2009.

[†] Ullage is the amount of chamber volume that is not filled by propellant. Increased ullage decreases chamber pressure by Boyle's law resulting in further decreases in propellant burn rate. Thus, relatively small increases in ullage may be anticipated to discernibly reduce muzzle velocity.

CONCLUSIONS

A truly large caliber rarefaction wave gun has been designed, fabricated, and is currently undergoing test and validation. It has been successfully integrated with an unusual swing-chamber munitions handling interface. This interface allows straightforward combat system integration of this armament technology.

REFFERENCES

[1] Kathe, E, Miner K., and Dillon, R., "Rarefaction Wave Gun Tank Main Armament Demonstrator," 26th Army Science Conference, Orlando, FL, December 2008.

[2] Gough, P. S., The XNOVAKTC Code, Portsmouth, NH, 1990.

[3] Kathe, E., Dillon, R., Sopok, S., Witherell, M., Dunn, S., and Coats, D., 2001 Rarefaction Wave Gun Propulsion, JANNAF 50th Propulsion Meeting, Salt Lake City, UT.

[4] Kathe, E., 2002, Rarefaction Wave Gun Propulsion, Doctoral Thesis, Rensselaer Polytechnic Institute, Troy, NY, 298.

[5] Coffee, T. P., 2006, Modeling the 35mm Rarefaction Wave Gun, JANNAF 2006-0166J.

[6] Chinn, G. M., 1955, The Machine Gun, Volume IV, Department of the Navy.

Table 1. Predicted and Experimental Results.

Shot number			4	5	10	11	9	12	6	7	8		17
Date (2008)			5/19	8/13	10/10	10/15	10/1	10/22	8/27	9/4	9/10		TBD
Parametric Configuration	Distance to Vent	mm	50	43	36	26	12	43	36	26	19		Closed
	Projectile Mass	Kg	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31		8.31
	Charge Mass	Kg	6.78	6.75	6.80	6.80	6.81	6.97	7.05	6.98	6.98		7.0
			Group A ~ 6.8					Group B ~ 7.0					
	Chamber Volume	L	7.71	7.78	7.84	7.95	8.10	7.78	7.84	7.95	8.02		7.73
Predicted Results	Muzzle Velocity	km/s	1.50	1.49	-	-	-	-	1.55	-	-		1.57
	Max Pressure	MPa	563	551	-	-	-	-	643	-	-		669
	Momentum	kNs	14.7	14.0	-	-	-	-	14.4	-	-		24.2
Experimental Results	Muzzle Velocity	km/s	1.34	1.38	1.35	1.31	1.20	1.38	1.38	1.35	1.35		-
	Max Pressure	MPa	389	-	402	383	315	-	447	416	395		-
	Momentum	kNs	12.9	12.7	12.7	12.8	7.4	12.9	12.6	12.7	13.1		-